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DESIGN METHOD FOR FOUR-REFLECTOR TYPE BEAM WAVEGUIDE FEED SYSTEMS

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Abstract This article discusses a method for the design of four-reflector type beam waveguide feed systems, comprised of a conical horn and 4 focused reflectors, which are used widely as the primary reflector systems for communications satellite earth station antennas. The design parameters for these systems are clarified, the relations between each of the parameter are brought out based upon the beam mode development [3], and the independent design parameters are specified. The characteristics of these systems, namely spillover loss, crosspolarization components, and frequency characteristics, and their relation to the design parameters, are also shown. It is also indicated that design parameters which decide the dimensions of the conical horn or the shape of the focused reflectors can be unerringly established once the design standard for the system has been selected as either (I) minimizing the crosspolarization component by keeping the spillover loss to within acceptable limits or (II) minimizing the spillover loss by maintaining the crossover components below an acceptable level and the independent design parameters, such as the respective sizes of the focused reflectors and the distances between the focused reflectors, etc., have been established according to mechanical restrictions. A sample design is also shown. In addition to being able to clarify the effects of each of the design parameters on the system and improving insight into these systems, the efficiency of these systems will also be increased with this design method.

1. Preface

Beam waveguide feed systems, comprised of a conical horn and several focused reflectors, are widely used as the primary reflector systems of large diameter antennas, such as communications satellite earth station antennas or radio telescopes [1],[2]. Radio waves which have been collected by the main and sub-reflectors can be transmitted to a conical horn which is fixed on the earth through these beam waveguide feed systems. Because of this, ease of maintenance and application are provided since the branching feed devices, transmitters, and receivers connected to the conical horn can also all be

* Numbers in the margin indicate pagination in the foreign text.

established on the ground.

A design method using beam mode development has already been reported as a method for the design of these beam waveguide feed systems [3]. In this article, that method is applied to the design of four-reflector type beam waveguide feed systems which are being widely used as antennas for satellite communication earth stations. First, the design parameters and their relation to each other will be explored, and the independent design parameters will be clarified. Then, the relation between the design parameters and spillover loss, crosspolarization components and frequency characteristics in the beam waveguide feed system will be shown. It will be shown therein that crosspolarization and spillover loss can be minimized by establishing the independent design parameters, such as the respective sizes of the focused reflectors or the distances between each of the focused reflectors, according to mechanical restrictions.

2. Design system for four-reflector beam waveguide feed systems

2.1 Essential properties and design parameters

Beam waveguide feed systems are used widely in satellite communications earth station antennas, etc. The following conditions must be fulfilled in these feed systems.

(1) In fully directional antennas which perform both azimuth (A_z) and elevation (E_l) rotation, the feed horn and branch feed devices, transmitters and receivers connected to it must be constructed so that they can be positioned where they

will not be subject to the A_Z-E_1 rotations.

(2) The radio waves collected by the main and sub-reflectors must be transmitted to a stationary feed horn with low loss.

(3) The crosspolarized component developed by this beam waveguide feed system must retain a great deal of polarization discrimination when used in conjunction with orthogonal bipolar waves.

(4) Frequency fluctuations in gain and crosspolarization levels must be minimal across all transmitting and receiving bands.

(5) When the objective of the system, such as a satellite, is tracked by a higher mode monopulse system, tracking performance must not be lost due to the development of unnecessary higher modes by this feed system.

From these conditions, four-reflector beam waveguide feed /623
systems which are comprised of 4 focused reflectors and a conical horn, as shown in Figure 1, are in wide use. In these feed systems, the fourth focused reflector is subject to A_Z and E_1 rotation together with the main and sub-reflectors, while the first through third focused reflectors are constructed for only A_Z rotation, so that the central axis of the beam of incident waves radiated into each

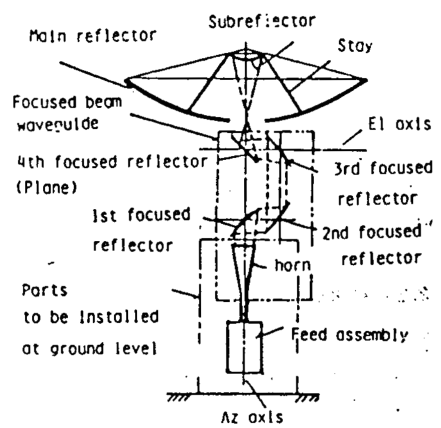

図1 衛星通信地球局アンテナの構成
Fig.1 - Configulation of an earth station antenna for setellite communication.

of the focused reflectors is perpendicular to the central axis of the beam subsequently reflected from each focused reflector. The fourth and third focused reflectors face each other with the E_1 axis as their central axis, while the first focused reflector faces the conical horn, which is positioned with the A_z axis as its central axis. The feed horn and feed equipment are stationed on the ground, with the space between the feed horn and the first focused reflector fulfilling the role of a rotary joint for A_z rotation and the space between the third and fourth focused reflectors likewise becoming a rotary joint for E_1 rotation. Consequently, the radiation pattern of the horn must be made radially symmetrical along the A_z axis and the fourth focused reflector must be flat since the radiation properties of the antenna are unchanged by the A_z-E_1 rotation.

The design parameters for these feed systems are, as shown in Figure 2, the aperture diameter and length of the feed horn, D_0, R_0, the aperture diameter of each of the focused reflectors, D_1, D_2, D_3, D_4, the distance between the center points of each of the focused reflectors, d_0, d_1, d_2, d_3, d_4, the focal gaps when the focused reflectors are replaced with lenses [5], f_1, f_2, f_3, and the aperture diameter of the sub-reflector, D_5. The subscripted numeral $_i$, i.e. D_i, d_i, f_i, corresponds to the respective numbers of the focused

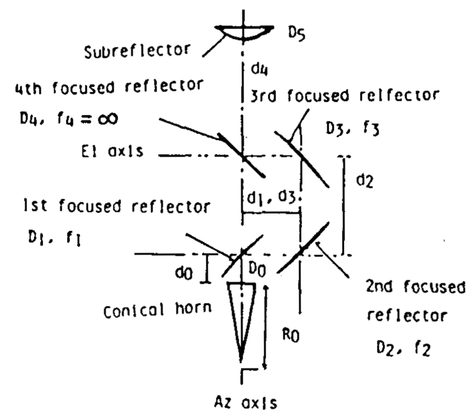

図2 4枚反射鏡集束ビーム給電系の設計パラメータ
Fig.2 - Design parameters of a four-reflector type beam waveguide feed.

reflectors.

The aperture diameter of the sub-reflector, D_5, herein, is established according to the aperture diameter of the main reflector to optimize the radiation characteristics of the antenna, a diameter of 1/10 that of the main reflector normally being selected [6]. Also. the minimum value which can be realized for d_4 is determined by the mechanical design of the main and sub-reflectors. The minimum practical value for d_2 is also determined from the mechanical design for E_1 rotation, such as gears, etc. The minimum values for d_1 and d_3 are determined so that the beam reflected from each of the focused reflectors is not blocked by one of the other focused reflectors. D_3, D_2, and D_1 are preferably large from an electrical aspect, but in order to keep their overall mechanical size to within desired limits, an upper limit is established. Also, from the minimum blocking conditions for Cassegrain antennas [4], $D_4 \leq D_5$. Consequently, the only design parameters which can be chosen with relative freedom are the focal gaps f_i and the dimensions of the feed horn D_0, R_0.

From the above conditions, the following are design goals for beam waveguide feed systems.

(a) To minimize spillover loss from each of the focused reflectors.

(b) To minimize the crosspolarized component at the sub-reflector.

(c) To reduce frequency fluctuations in the electrical field distribution at the sub-reflector.

In this article, D_5, D_4, D_3, D_2, and D_1 and d_4, d_3, d_2, d_1, and d_0 will be given, while the means for unmistakenly establishing the remaining parameters, f_4, f_2, and f_3 and D_0 and R_0, from the above-mentioned electrical characteristics will be shown. If, as a result, the desired characteristics are not obtained, it will be necessary to change the values for the parameters given above and repeat the method of this article.

2.2 The beam mode between two reflectors

The space between the two reflectors, #1 and #2, shown in Figure 3, can be considered as only propagating a dominant beam mode.

First, the constants of the beam radii, ω_2 and R_2, on the /624

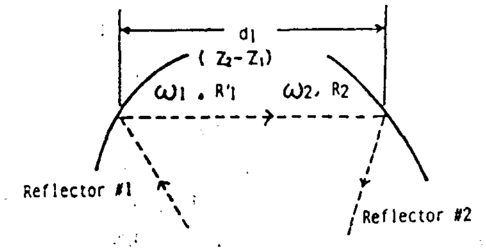

図3 2枚の反射鏡
Fig.3-Two reflectors.

second reflector surface, which is separated from the first reflector by a distance of only d_1, are derived when the radius of the beam on the reflected side of the first reflector surface, ω_1, and the curve radius of the wave plane, R'_1, are given. Hereinafter, items denoted with a " ' " are parameter of the reflected side.

The following relations become true when the beam radius of the beam waste is ω_0 and the distances from the beam waste to the reflectors #1 and #2 are z_1 and z_2.

$$\left.\begin{aligned} \nu_1' &= \frac{\pi \omega_1^2}{\lambda R_1'} \\ \omega_0 &= \omega_1 / \sqrt{1+\nu_1'^2} \\ z_1 &= R_1' / (1 + 1/\nu_1'^2) \end{aligned}\right\} \quad (1)$$

$$z_2 = z_1 + d_1 \quad (2)$$

$$\left.\begin{aligned} \nu_2 &= \frac{\lambda z_2}{\pi \omega_0^2} \\ \omega_2 &= \omega_0 \sqrt{1+\nu_2^2} \\ R_2 &= z_2 (1 + 1/\nu_2^2) \end{aligned}\right\} \quad (3)$$

The following formulae are obtained from these relations.

$$\left.\begin{aligned} \nu_2 &= \nu_1' + \frac{\lambda d_1}{\pi \omega_1^2}(1+\nu_1'^2) \\ \omega_2 &= \omega_1 \sqrt{\frac{1+\nu_2^2}{1+\nu_1'^2}} \end{aligned}\right\} \qquad (4)$$

Next, the beam mode constant

$$u_1 = \frac{\pi \omega_1 \omega_2}{\lambda d_1} \qquad (5)$$

when the beam radii on the two reflectors, ω_1 and ω_2, have been provided is defined and the following formula is obtained using the results of formula (4).

$$\left.\begin{aligned} \nu_1' &= -\frac{\omega_1}{\omega_2} u_1 + \varepsilon_1 \sqrt{u_1^2 - 1} \qquad (\varepsilon_1 = \pm 1) \\ \nu_2 &= \frac{\omega_2}{\omega_1} u_1 - \varepsilon_1 \sqrt{u_1^2 - 1} \end{aligned}\right\} \qquad (6)$$

Consequently, it becomes necessary for ω_1 to fulfill the following condition.

$$u_1 \geqq 1 \qquad (7)$$

According to formula (6), two (2) types of beam modes exist in which ω_1, ω_2 and d_1 are the same. Now, from the relation

$$\varepsilon_1 \sqrt{u_1^2 - 1} = \nu_1' + \frac{\omega_1}{\omega_2} u_1 = \frac{\pi \omega_1^2}{\lambda}\left(\frac{1}{R_1'} + \frac{1}{d_1}\right) \qquad (8)$$

ε_1 is represented as follows.

$$\varepsilon_1 = \mathrm{sign}\left(\frac{1}{R_1'} + \frac{1}{d_1}\right) \qquad (9)$$

2.3 Relations between beam mode parameters

When the beam radii, ω_n, are provided for each of the reflectors, the following relation exists between the focal gaps, f_n, of each of the reflectors [5] and the beam mode parameters, using the results from section 2.2.

$$\left.\begin{aligned}
&\frac{1}{f_n}=\frac{1}{R_n}-\frac{1}{R'_n}=\frac{\lambda}{\pi\omega_n^2}(v_n-v'_n)\\
&v'_n=\frac{\pi\omega_n^2}{\lambda R'_n}=-\frac{\omega_n}{\omega_{n+1}}u_n+\epsilon_n\sqrt{u_n^2-1}\\
&v_{n+1}=\frac{\pi\omega_{n+1}^2}{\lambda R_{n+1}}=\frac{\omega_{n+1}}{\omega_n}u_n-\epsilon_n\sqrt{u_n^2-1}\\
&u_n=\pi\omega_n\omega_{n+1}/(\lambda d_n)\\
&\epsilon_n=\mathrm{sign}(1/R'_n+1/d_n)
\end{aligned}\right\} \quad (10)$$

Wherein, R_n and R'_n represent curve radii of the wave planes of the incident side and reflected side of each reflector, respectively, as the electrical wave advance from the conical horn toward the sub-reflector, this being a positive value when the wave plane is convex in relation to its direction of progress, and a negative value when the wave plane is concave in relation to its direction of progress.

When the conical horn is a Colgate horn, possessing a radially symmetrical radiation pattern, v_1 and ω_1 possess the following relation to the parameters of the conical horn, d_0, D_0, and R_0.

$$\left.\begin{aligned}
&v_1=v_0+\frac{d_0}{R_0}\left(v_0+\frac{1}{v_0}\right)\\
&v_0=\frac{\pi\omega_0^2}{\lambda R_0}\\
&\omega_0=\frac{D_0}{2\Omega_0}\\
&\omega_1=\omega_0\sqrt{\frac{1+v_1^2}{1+v_0^2}}
\end{aligned}\right\} \quad (11)$$

Wherein, ω_0 is 1.5539 when the conical horn is a Colgate horn [3].

According to formula (10), the following relation exists between ω_3, ω_4, ω_5, d_3, and d_4 when the reflector #4 is a flat reflector.

First, when ω_3, ω_4, d_3, and d_4 are given,

$$\left.\begin{aligned}
&v_3' = -\frac{\omega_3}{\omega_4}u_3 + \varepsilon_3\sqrt{u_3^2 - 1}\\
&u_3 = \pi\omega_3\omega_4/(\lambda d_3)\\
&v_5 = v_3' + \frac{\lambda(d_3+d_4)}{\pi\omega_3^2}(1+v_3'^2)\\
&\omega_5 = \omega_3\sqrt{\frac{1+v_5^2}{1+v_3'^2}}
\end{aligned}\right\} \quad (12)$$

is true, and when ω_3, ω_5, d_3, and d_5 are given, /625

$$\left.\begin{aligned}
&v_3' = -\frac{\omega_3}{\omega_5}u_3' + \varepsilon_3\sqrt{u_3'^2 - 1}\\
&u_3' = \frac{\pi\omega_3\omega_5}{\lambda(d_3+d_5)}\\
&v_4 = v_3' + \frac{\lambda d_3}{\pi\omega_3^2}(1+v_3'^2)\\
&\omega_4 = \omega_3\sqrt{\frac{1+v_4^2}{1+v_3'^2}}
\end{aligned}\right\} \quad (13)$$

is true.

According to the following results, the independent parameters which determine the beam mode are d_0, d_1, d_2, d_3, d_4, v_1, ω_1, ω_2, ω_3, ω_5 (or ω_4), and ε_1, ε_2, ε_3. Now, according to formula (11), D_0 and R_0 may be selected in place of v_1 and ω_1.

2.4 Spillover loss and design parameters

When the edge level of each of the reflectors is $-L_n$(dB)($L_n>0$) and the beam radii at each reflector surface is ω_n, the following relation exists between these values.

$$\omega_n = \frac{D_n}{2}\sqrt{\frac{20\log_{10}e}{L_n}} \quad (14)$$

Wherein, D_n is the aperture diameter of the respective reflector and e=2.718.

From formula (7) in the previous section, the following relation must be true between the beam radii of adjacent reflectors.

$$\frac{\pi \omega_n \omega_{n+1}}{\lambda d_n} \geqq 1 \qquad (15)$$

Using formulae (14) and (15), the conditions between the edge levels of each reflector are determined and the following becomes true.

$$\left. \begin{aligned} & L_n \cdot L_{n+1} \leqq L_{n\,max}^2 \\ & L_{n\,max} = 6.82 \left(\frac{D_n D_{n+1}}{\lambda d_n} \right) \end{aligned} \right\} \qquad (16)$$

In addition, the following relation exists between the edge level and the spillover loss, ΔP_n.

$$\left. \begin{aligned} \Delta P_n &= 1 - e^{-2t_e^2} \\ &\quad (\text{基本ビームモード},\ m=-1,\ n=0) \\ &= 1 - (2t_e^2 + 1) e^{-2t_e^2} \quad (\text{高次ビームモード},\ m=0 \text{ or } -2,\ n=0) \\ t_e &= \sqrt{\frac{L_n}{20 \log e}} \end{aligned} \right\} \qquad (17)$$

Consequently, according to formulae (16) and (17), a practical and possible minimum spillover loss amount is derived when an upper limit is determined for the reflector aperture diameters and their intervening gaps. Spillover loss thus decreases as the reflector aperture diameters become larger and their intervening spaces become smaller. Also, when the maximum allowable amount of spillover loss is provided, the acceptable edge level range, and consequently, the range for ω_n' can be determined.

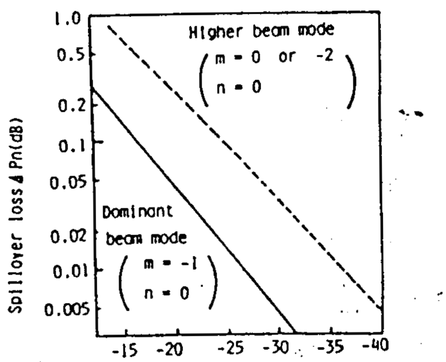

図4 エッジレベルとスピルオーバ損失
Fig.4 - Relation between edge level and spillover loss.

The relation between ΔP_n and L_n is shown in Figure 4. According to formula (7), when L_n

is sufficiently larger than $20\log_e$, the spillover loss (dB) of the higher beam mode is approximately $2t_e^2$ times that of the dominant beam mode. Consequently, in systems in which the satellite is tracked by a higher mode monopulse system, it is necessary to determine the edge level, taking into consideration loss in the higher beam mode used for error signal detection in automatic tracking.

2.5 Crosspolarization component at the sub-reflector

From formula (30) in the referenced material [3], the sum of the crosspolarization component which has developed through the four focused reflectors and up to the sub-reflector is as follows.

$$\left.\begin{aligned} C &= \frac{1}{\sqrt{2\epsilon}}\left|\frac{\omega_1}{f_1}e^{j\theta_1}+\frac{\omega_2}{f_2}-\frac{\omega_3}{f_3}e^{-j\theta_2}\right| \\ e^{j\theta_1} &= (\epsilon_1\sqrt{u_1^2-1}+j)/u_1 \\ e^{-j\theta_2} &= (\epsilon_2\sqrt{u_2^2-1}-j)/u_2 \end{aligned}\right\} \quad (18)$$

Wherein, C is the electrical field ratio of the maximum value for the crosspolarization component and the maximum value for the principle polarization component at the sub-reflector position.

Also, since θ_1 and θ_2 are values within $[0,\pi]$, as is clear from the above formula, a system in which absolutely no crosspolarized waves are developed cannot be constructed only from concave reflectors ($f_n>0$). Consequently, a system in which absolutely no crosspolarization is developed by containing not only concave reflectors, but convex reflectors as well, can be realized by providing a two of the beam mode parameters shown in section 2.3 with different parameter functions.

By substituting formula (10) for the crosspolarization elimination condition C=0,

$$\frac{(\varepsilon_1\sqrt{u_1^2-1}+j)}{u_1}\left(\frac{v_1-v_1'}{\omega_1}\right)+\left(\frac{v_2-v_2'}{\omega_2}\right) -\frac{(\varepsilon_2\sqrt{u_2^2-1}-j)}{u_2}\left(\frac{v_3-v_3'}{\omega_3}\right)=0 \tag{19}$$

namely, /626

$$\left.\begin{aligned} &\frac{v_1-v_1'}{u_1\omega_1}+\frac{v_3-v_3'}{u_2\omega_3}=0\\ &\frac{\varepsilon_1\sqrt{u_1^2-1}}{u_1}\left(\frac{v_1-v_1'}{\omega_1}\right)+\left(\frac{v_2-v_2'}{\omega_2}\right)\\ &\quad-\frac{\varepsilon_2\sqrt{u_2^2-1}}{u_2}\left(\frac{v_3-v_3'}{\omega_3}\right)=0 \end{aligned}\right\} \tag{20}$$

becomes true. When

$$S=\omega_2\frac{v_3-v_3'}{u_2\omega_3} \tag{21}$$

this becomes a function of the parameters other than ω_1 and R_1.

$$\left.\begin{aligned} &v_1=v_1'-\frac{\omega_1}{\omega_2}u_1 S\\ &v_2-v_2'=(\varepsilon_1\sqrt{u_1^2-1}+\varepsilon_2\sqrt{u_2^2-1})S\\ &\quad=\frac{\pi\omega_2^2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)-(\varepsilon_1\sqrt{u_1^2-1}+\varepsilon_2\sqrt{u_2^2-1}) \end{aligned}\right\} \tag{22}$$

is obtained, using the results from formula (20) and formula (6). According to the second equation of the above formula,

$$\varepsilon_1\sqrt{u_1^2-1}=\frac{1}{1+S}\frac{\pi\omega_2^2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)-\varepsilon_2\sqrt{u_2^2-1}$$
$$=V \tag{23}$$

becomes true, but this is also a function for the parameters other than ω_1 and R_1. Consequently, when formulae (22) and (23) are used, ω_1 and R_1 become

$$\left.\begin{aligned} &\varepsilon_1=\mathrm{sign}(V)\\ &\omega_1=\frac{\lambda d_1}{\pi\omega_2}\sqrt{1+V^2}\\ &v_1'=-\frac{\omega_1}{\omega_2}u_1+V\\ &v_1=v_1'-\frac{\omega_1}{\omega_2}u_1 S=V-\frac{\pi\omega_1^2}{\lambda d_1}(1+S)\\ &R_1=\frac{\pi\omega_1^2}{\lambda v_1}=\frac{d_1}{V\frac{\lambda d_1}{\pi\omega_1^2}-(1+S)} \end{aligned}\right\} \tag{24}$$

and ω_1 and R_1 are derived as functions of the other parameters. The parameters, DO and RO, of the Colgate horn which is being applied here can also be derived from formula (11).

Consequently, given the values for d_0, d_1, d_2, d_3, d_4, ω_3, ω_5, ε_2, ε_3, and the frequency, the values for D_0 and R_0 when the value for ω_2 fluctuates can be determined. Incidentally, ω_4 can be given in place of ω_5.

However, there are instances in which the value for R_0 which is derived by the above sort of method is either extremely large or extremely small, making it an impractical dimension. In this case, it becomes necessary to find a system which minimizes the value for C in formula (18). This results in one of the parameters being derived as the function of another parameter.

2.6 Frequency characteristics of the electrical field distribution at the sub reflector

The wide band design condition [3],[5] which stabilizes the beam radius and the curve radius of the incidence wave plane against the frequency on the sub-reflector using a single feed horn is the matching of the feed horn image with the position of the sub-reflector through the reflector system.

In the case of a four-reflector beam waveguide feed system, when the distance between the image on the sub-reflector and the first focused reflector is d'_0, the following becomes true.

$$\left.\begin{aligned} \frac{1}{x_1} &= \frac{1}{f_3} - \frac{1}{d_3+d_4} \\ \frac{1}{x_2} &= \frac{1}{f_2} - \frac{1}{d_2-x_1} \\ \frac{1}{d'_0} &= \frac{1}{f_1} - \frac{1}{d_1-x_2} \end{aligned}\right\} \qquad (25)$$

Wherein,

$$d_0'/d_0 = 1 \tag{26}$$

becomes the wide band design condition.

2.7 Selection of design parameters

According to the items explained above, it would be appropriate to select the following as the design parameters for a four-reflector beam waveguide feed system.

wavelength	: λ
parameters which determine the exterior shape of the system	: D_1, D_2, D_3, D_4, D_5, d_0, d_1, d_2, d_3, d_4
primary radiator parameters	: D_0 (or aperture angle, $2\phi_0$), R_0
beam mode parameters	: ω_2, ω_3, ω_5, ε_1, ε_2, ε_3

By selecting parameters in this way, the spillover loss of the system can easily be determined using formula (17). The focal gaps of the focused reflectors can also be derived using formula (10), the amount of crosspolarization developed can be shown by formula (18), and the frequency characteristics can be shown by formula (26).

3. Design criteria and a sample design

3.1 Design criteria

When attention is paid to spillover loss and crosspolarization, the targets of design, the following design criteria are considered in the determination of the beam mode parameters.

(I) The minimization of crosspolarization component through the maintenance of spillover loss within allowable values.

(II) The minimization of spillover loss through the maintenance of crosspolarization component at below an allowable value. /627

When the exterior shape and the wavelength of the system is determined through the relation in formula (16), there is a lower limit to the amount of spillover loss which can be realized. However, when limits are not placed on spillover loss, the lower limit for crosspolarization component is 0, as is understood from the results of section 2.4 and from the fact that crosspolarization does not develop when all of the focused reflectors are flat.

The relation shown in formula (15) exists between the beam radii, ω_n and ω_{n-1}, on adjacent reflectors and when the spillover loss, ΔP_n, namely, L_n, for this section is given, the upper limit for ω_n is determined through formula (14) and the range for ω_n becomes the following.

$$\left.\begin{aligned} &K_n D_n \geqq \omega_n \geqq \frac{\lambda}{\pi} \frac{d_{n-1}}{D_{n-1}} \frac{1}{K_{n-1}} \\ &K_n = \frac{1}{2}\sqrt{\frac{20 \log e}{L_n}} \end{aligned}\right\} \tag{27}$$

Normally, the distance between the third focused reflector and the sub-reflector (d_3+d_4) is long, the distance between the second and third focused reflectors (d_2) is relatively short, and the distance between the first and second focused reflectors (d_1) is even shorter. In order to minimize the amount of crosspolarization between the first and second focused reflectors, it is necessary that the curve radius of the wave plane on the reflectors is great, in which case, $\varepsilon_1=\varepsilon_2=1$, from the results of formula (6). Next, it would be appropriate to make $\varepsilon_3=-1$ in order to lower the amount of spillover underneath the limited aperture diameter of the sub-reflector, thus creating a negative curve radius in the reflected wave at the third focused reflector. In this case, the spillover loss in the transmission between the second and third focused reflectors increases, making it necessary to make the edge levels of these two focused reflectors equal through formula (16) in order to minimize this spillover loss. Namely, it is necessary that $L_2=L_3$, or that $\omega_2/\omega_3=D_2/D_3$.

Also, the design parameters ω_1 and ε_1 are automatically determined when the first focused reflector is a flat reflector.

When the beam radius at the sub-reflector, ω_5, is selected within an allowable range from the design conditions of the main-sub-reflector system, the upper and lower limits for ω_2 and ω_3 are determined through formula (27) according to the allowable spillover loss in the second and third focused reflectors. When this ω_3 (ω_2) is caused to fluctuate within the allowable range, the spillover loss increases regularly with increases in ω_3, but whether crosspolarization increases or decreases regularly, the amount of fluctuation in either case is extremely small.

3.2 Sample design

A case in which the values shown in Table 1 are given, based on the thinking in section 2.1, as the parameters which determine the exterior shape of the system, i.e. the size of each of the focused reflectors and the distances between the focused reflectors, will be discussed as a sample design.

Table 1
Design Parameters

D_1	2.5m	d_0	2.0m
D_2	3.6m	d_1	3.15m
D_3	3.6m	d_2	13.5m
D_4	2.9m	d_3	5.4m
D_5	6.0m	d_4	29.95m

In this case, $f_1=\infty$, $\delta_1=\varepsilon_2=1$, $\varepsilon_3=-1$, and $\lambda=0.124$m.

First, the beam diameter on the sub-reflector, ω_5, and the dimensions of the feed horn, D_0 and R_0, were established, and the results from determining the spillover loss ΔP and crosspolarization component C for the entire system by fluctuating the diameter of the beam on the third focused reflector, ω_3, are shown in Figure 5. According to this, ω_3 can be determined by either of the above-mentioned criteria, (I) or (II).

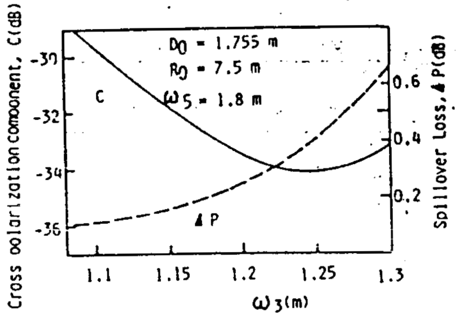

図5 ω_3に対する交差偏波成分，スピルオーバ損失の変化
Fig.5 - Relation between ω_3 and cross polarization component, spillover loss.

Also, Figure 6 is the result of determining $_3$ through the design criterion (II) from Figure 5 and then deriving the spillover loss, using ω_5 as a parameter. By these steps, the values for ω_3 and ω_5, namely the shape of the second and third focused reflectors, can be unerringly

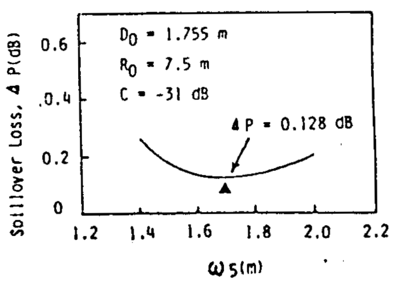

図6 ω_5に対するスピルオーバ損失の変化〔設計基準(II)〕
Fig.6 - Relation between ω_5 and spillover loss, design criterion (II).

determined according to the dimensions of the feed horn. /628
Consequently, it then becomes possible to determine the parameters which will optimize the characteristics of the system based on the mechanical limitations of the dimensions of the feed horn.

The values for d'_0/d_0 and ΔP(dB), which were obtained by design criteria (I) and (II), by using the opening angle of the feed horn, $2\phi_0$, and fluctuating the the length of the horn, R_0, are shown in Figures 7 and 8. Through these sort of steps, the mechanism for fluctuating the characteristics of the system become apparent and the values for each of the parameters can be unerringly determined based on the controlled conditions.

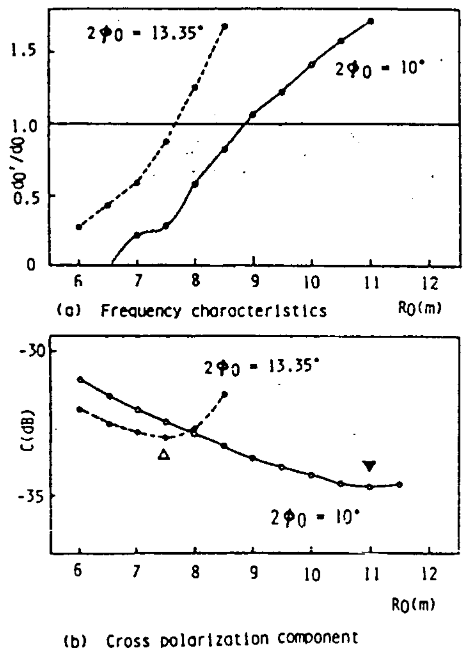

図7 設計基準(I)で求めた周波数特性，交差偏波成分 (ΔP=0.2 dB)

Fig.7 - Frequency characteristics and cross polarization component obtained by design criterion (I), (ΔP=0.2 dB).

In the system obtained by design criterion (II), it appears that there is an correlation between when the spillover loss is minimized and when the frequency characteristics are optimized, but this is accidental. This is because spillover loss can be changed by changing the diameters of each of the focused reflectors without changing the frequency characteristics or the crosspolarization characteristics.

Similarly, there is no correlation between when the crosspolarization component is minimized and when the frequency characteristics are optimized. This is because the values for d_0, as well as for R_0 and ϕ_0, can be changed without changing the spillover loss or the crosspolarization component at all, in which case, only the frequency characteristics are changed.

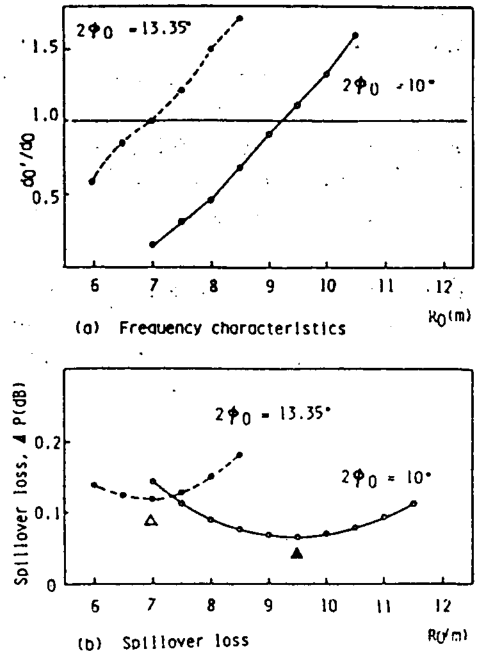

図8 設計基準(II)で求めた周波数特性，スピルオーバ損失

Fig.8 - Frequency characteristics and spillover loss ($C = -31$ dB) obtained by design criterion (II), ($C = -31$ dB).

If the anticipated performance is not realized by the above-mentioned means, the the above-mentioned steps are repeated, altering the restrictions on the parameters which determine the exterior shape of the system. For example, it is desirable to reduce the size of the focused reflectors as much as possible from the point that it will miniaturize the beam waveguide feed system and make it more lightweight, but when spillover loss becomes a problem, spillover loss can be reduced by altering this restriction and enlarging the reflectors, without changing any of the other characteristics.

3.3 Values and comparisons calculated through beam mode development

Through beam mode development [3] about the designed system, the characteristics of the system can be calculated up to high beam modes and these results can be compared to the results of the design used only with dominant beam mode. Calculations in this case were made on a case in which the values for design criterion (II) were $2\phi_0=13.35°$ and $R_0=7m$. Those results are shown in Table 2.

Table 2
Precision of Design System

Item		Design System	Beam Mode Devlp.
Crosspolarization Cmpnt C		-31 dB	-31.3 dB
Spillover loss (addtn. integration)	reflector #1	0.017 dB	0.080 dB
	" #2	0.034 dB	0.109 dB
	" #3	0.136 dB	0.148 dB
	" #4	0.164 dB	0.148 dB
	" #5	0.170 dB	0.186 dB

4. Conclusion /629

The design parameters and their relation to one another for four-reflector beam waveguide feed systems were clarified in the above. (I) The minimization of crosspolarization component through the maintenance of spillover loss within allowable values, and (II) the minimization of spillover loss through the maintenance of crosspolarization component at below an allowable value were also shown as design criteria by considering the demands required by the system concerning spillover loss, crosspolarization component, and frequency characteristics, and it was shown that the other design parameters could be obtained when these criteria were implemented and the controlled mechanical conditions, i.e. the sizes of each of the focused reflectors and the distances between the focused reflectors, were provided. The facts that the variation of the wave plane from a flat plane is small and that the primary beam mode is the dominant mode are preconditions for this design method [3], but these conditions are generally fulfilled in actual beam waveguide feed systems.

Through a method of this type, in addition increased understanding of the system and clarification of the influences each of the system parameters on the characteased understanding of the system and clarification of the influences each of the system parameters on the characteristics of the system, this method also provides increased efficiency in the design of these systems.

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16. Abstract

Abstract This article discusses a method for the design of four-reflector type beam waveguide feed systems, comprised of a conical horn and 4 focused reflectors, which are used widely as the primary reflector systems for communications satellite earth station antennas. The design parameters for these systems are clarified, the relations between each of the parameter are brought out based upon the beam mode development [3], and the independent design parameters are specified. The characteristics of these systems, namely spillover loss, crosspolarization components, and frequency characteristics, and their relation to the design parameters, are also shown. It is also indicated that design parameters which decide the dimensions of the conical horn or the shape of the focused reflectors can be unerringly established once the design standard for the system has been selected as either (I) minimizing the crosspolarization component by keeping the spillover loss to within acceptable limits or (II) minimizing the spillover loss by maintaining the crossover components below an acceptable level and the independent design parameters, such as the respective sizes of the focused reflectors and the distances between the focused reflectors, etc., have been established according to mechanical restrictions. A sample design is also shown. In addition to being able to clarify the effects of each of the design parameters on the system and improving insight into these systems, the efficiency of these systems will also be increased with this design method.

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